Project	AtlantOS – 633211
Deliverable number	D4.5
Deliverable title	Gap analysis of links between coastal and open ocean networks
Description	Report setting out recommendations to re-plan and optimise current observational strategies for continental shelf observing networks; and improve their connection with wider ocean observing networks.
Work Package number	4
Work Package title	Interfaces with coastal ocean observing systems
Lead beneficiary	IFREMER
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Submission data	
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Comments	

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Stakeholder engagement <u>relating to this task</u>*

WHO are your most important stakeholders?	☐ Private company If yes, is it an SME ☐ or a large company ☐? X National governmental body X International organization ☐ NGO ☐ others Please give the name(s) of the stakeholder(s): …
WHERE is/are the company(ies) or organization(s) from?	X Your own country X Another country in the EU ☐ Another country outside the EU Please name the country(ies): …
Is this deliverable a success story? If yes, why? **If not, why?**	X Yes, because, after fruitful discussions, we improved the view of the gaps between coastal and open ocean observing systems. ☐ No, because …..
Will this deliverable be used? **If yes, who will use it?** **If not, why will it not be used?**	X Yes, by European programme and scientific groups to draw future strategy of the observation of the continuum from the coast to the open ocean. ☐ No, because …..

NOTE: This information is being collected for the following purposes:

1. To make a list of all companies/organizations with which AtlantOS partners have had contact. This is important to demonstrate the extent of industry and public-sector collaboration in the obs community. Please note that we will only publish one aggregated list of companies and not mention specific partnerships.
2. To better report success stories from the AtlantOS community on how observing delivers concrete value to society.

*For ideas about relations with stakeholders you are invited to consult <u>D10.5</u> Best Practices in Stakeholder Engagement, Data Dissemination and Exploitation.

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Executive summary

The **gap analysis** of observing systems presented in this report is focused on the evaluation of the continuum between coastal observations and open ocean observations (including the shelf-break transition region). Some recommendations are suggested with the aim of improving the efficiency of existing observing systems in coastal and open ocean regions.

Gaps in **Observing networks, Data availability, Sustainability and Technology** are considered.

Main recommendations following identified gaps can be summarized as:

- The spatial coverage of observing networks need to be improved **between the near-coast and open ocean observing systems.**
- The general lack of observations over the shelf break and the continental shelf can be improved based on opportunity measurements (*e.g.* Fishery Observing Systems).
- Continuous monitoring of the shelf waters is crucial supporting the continuity and success of active **operational numerical forecast models**.
- **Biogeochemical or biological observations** are lacking except near coast were regular sampling are performed.
- **Harmonization actions** need to be extended to the whole range of observing networks (particularly diverse in coastal area) in coastal and open oceans.
- **Coastal data availability** remains limited and international initiatives need to be supported.
- **Estimations of costs** are necessary to show that observing ocean from coast to open ocean has a low cost to society compared with other infrastructures (*e.g.* roads), and how they provide **benefits for the society**.
- There is a need for **standardizing technological modules** for continuous, affordable and efficient monitoring systems, particularly for the coastal ocean.

Introduction

In order to develop strategies for linking European coastal observing activities with open ocean observing activities in the Atlantic ocean, major observing gaps should be identified first.

The gap analysis presented in this report, which is based on the AtlantOS Deliverable D1.3 "Analysis of the capacities and gaps of the present Atlantic Ocean Observing System" (Figure 1), is focused on the evaluation of the continuum between coastal and open ocean observations (including the shelf-break transition region).

Derived from the gap analysis, a series of recommendations are suggested with the aim of improving the efficiency of existing observing systems in coastal and open ocean regions.

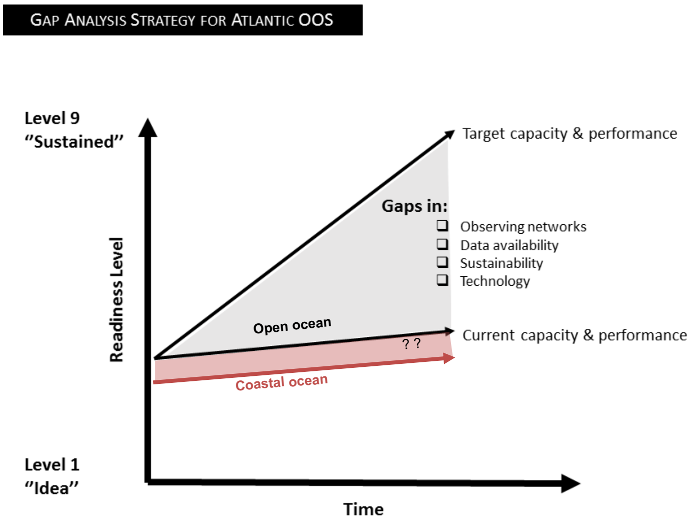

Figure 1 Gap analysis strategy for open and coastal oceans (modified from figure 6-1 in D.1.3). The figure gives a schematic overview of the gaps between the current and target observing network capacity and performance. For the coastal ocean, the present deliverable introduces the gaps between the common target for all observing networks and the current capacity and performance for coastal observing systems.

Coastal and open ocean observing networks

With the main objective of identifying the gaps in observing networks, an analysis based on the Essential Ocean Variables (EOVs - www.goosocean.org/eov) has been performed.
A geographical distribution of the different observing platforms measuring the Essential Ocean Variables in the Ireland-Biscay-Iberia and Atlantic North Western Shelf areas are represented in the maps in Figure 2 to Figure 7.

The number and geographical location of the observing platforms are taken from the available data in Coriolis (http://www.coriolis.eu.org) and Emodnet physics portal for the year 2017 (http://www.emodnet-physics.eu/Portal) in a geographical area between 20ºW-13ºE in longitude and 26ºN-65ºN in latitude. Note that platforms in the Baltic Sea, Skaggerak and Mediterranean Sea are masked out (shaded regions in Figure 2-Figure 7). The intended area here covers the Ireland-Biscay-Iberia and North-West Shelf regions. Here we distinguish coastal and open ocean observatories following the 200m depth contour, which is represented by the light grey line in Figure 2-Figure 8[1]; empty circle markers represent coastal observing platforms and filled markers represent open ocean observing platforms. The present document covers stationary and non-stationary platforms with available data on the Emodnet physics data portal. In terms of temporal appearance, we count each platform, present in the region within 2017. Thus in Figure 2-Figure 8, we demonstrate the first occurrence of each platform within the defined region during 2017.

For moving observations platforms like surface drifters, Ferry-boxes, Autonomous Surface Vehicles (ASVs) Gliders, Profiling floats, etc[2]. it is not straightforward to classify them as coastal (shallower than 200m depth) or offshore (deeper than 200m depth) observatories, as they can cover different areas. In the following analysis, they are classified according to area where their first measurement location is collected.

In the following, we show an analysis of the number of platforms with sensors measuring the different EOVs.

Temperature

There is a total of 412 in-situ observing platforms measuring Temperature in the defined area during 2017. 223 of these platforms are open ocean (deeper than 200m depth) platforms and 189 are coastal (shallower than 200m depth) platforms.

The geographical distribution of the observing platforms measuring Temperature is shown in Figure 2.

The distribution of these platforms by type is shown in Table 1. The contribution of profiling floats (92 platforms) and drifters (90 platforms) appears as the main source of Temperature measurements in open ocean. By comparison, very few coastal profilers (3 platforms) and drifting buoys (10 platforms) are deployed. Based on their locations, main areas with temperature observations are the open ocean and the shallower region of the continental shelf (along the coast) with a significant contribution of moored stations (94 platforms).

This distribution shows a balance between coastal (189 platforms) and open ocean (223 platforms) observing platforms. However, even if it is based on a very mature sensor technology, there is a gap of observations in the external and most extended part on continental shelf, adjacent to the shelf-break (considering the 200m depth isobath), where measurements are lacking.

[1] Acquiring data through Emodnet physics portal was not possible and therefore the data were kindly provided by Emodnet-help officers via a third-party online data storage system.

[2] Some observations from research vessels have also been considered if they are sent to the operational data portal. It appears through TESAC or CTD observations.

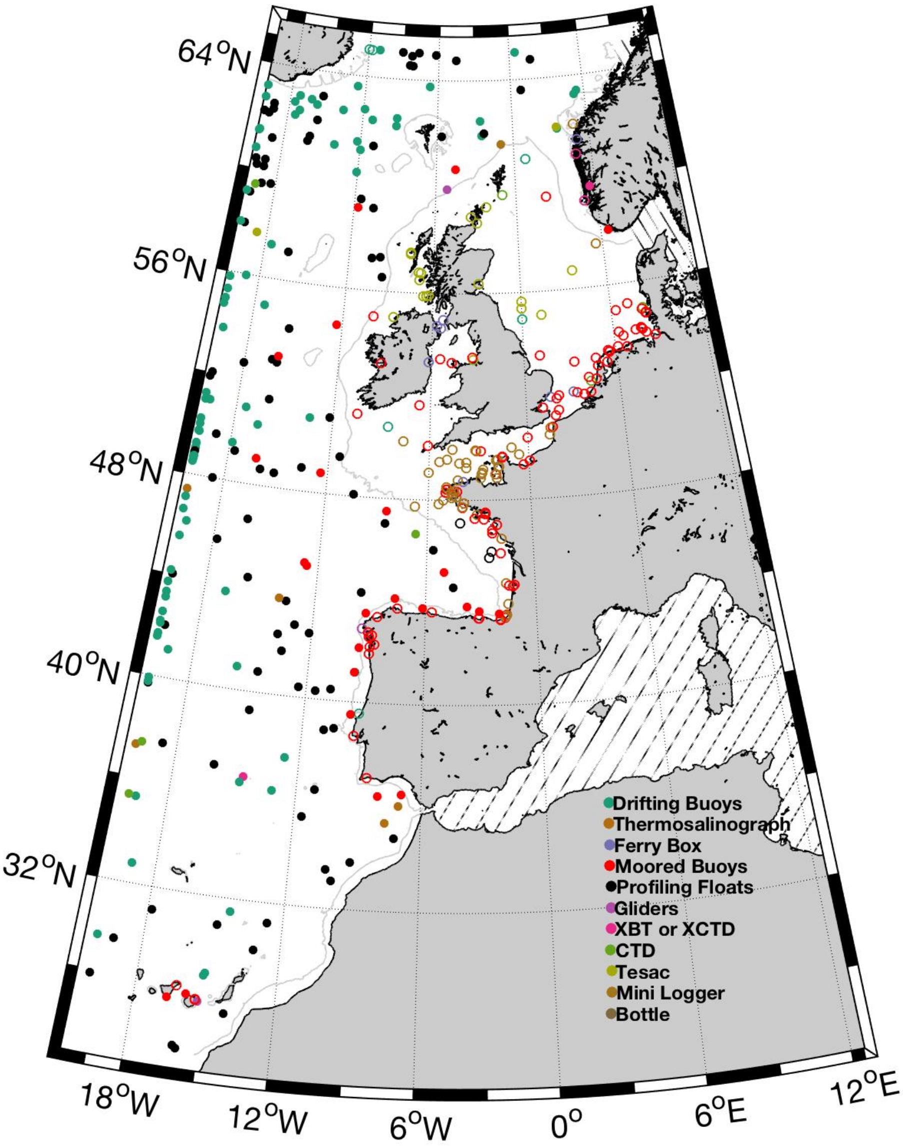

Figure 2 Distribution of in-situ platforms measuring Temperature, during 2017. The light grey line represents the 200m depth isobath considered as a limit between coastal and open ocean waters.

Table 1 Number and type of Open ocean and Coastal platforms measuring Temperature.

Observing Platform	Number of Open ocean Platforms (deeper 200m depth)	Number of Coastal Platforms (shallower 200m depth)
Profiling Floats	92	3
Moorings	25	94
Drifting Buoys	90	10
CTD	4	3
Tesac	2	19
Ferrybox	-	8
Thermosalinograph	5	9
Mini Logger used on Fishery Observing Systems	1	40
Glider	2	1
XBT or XCTD	2	2
Total	**223**	**189**

Salinity

There is a total of 214 in-situ observing platforms measuring Salinity in the defined area during 2017. 119 of these platforms are open ocean platforms and 95 were coastal platforms (Table 2). Geographical distribution of these observing platforms is given in Figure 3.

Measuring ocean salinity remains indeed a technological challenge due to issues like biofouling. We can notice that the number of moorings including salinity sensors is reduced compared to the number of temperature sensors (39 mooring with salinity against 94 moorings with temperature in the coastal ocean). In open ocean, salinity measurements are mainly from profiling ARGO floats (92 over 119). Along the coasts, some regions, like South-West of Spain, Portugal or Ireland are not well covered. Those geographical gaps could also be explained by data distribution issues despite existing observing systems. Ongoing projects and programmes will contribute to improve the visibility of coastal observing networks, via the improvement of data dissemination in European data portals.

Table 2 Number and type of Open ocean and Coastal platforms measuring Salinity.

Observing Platform	Number of Open ocean Platforms (deeper 200m depth)	Number of Coastal Platforms (shallower 200m depth)
Profiling Floats	92	3
Moorings	15	39
Drifting Buoys	-	-
CTD	-	2
Tesac	2	19
Ferrybox	-	2
Thermosalinograph	4	10
Mini Logger used on Fishery Observing Systems	-	17
Glider	2	1

XBT or XCTD	4	2
Total	**119**	**95**

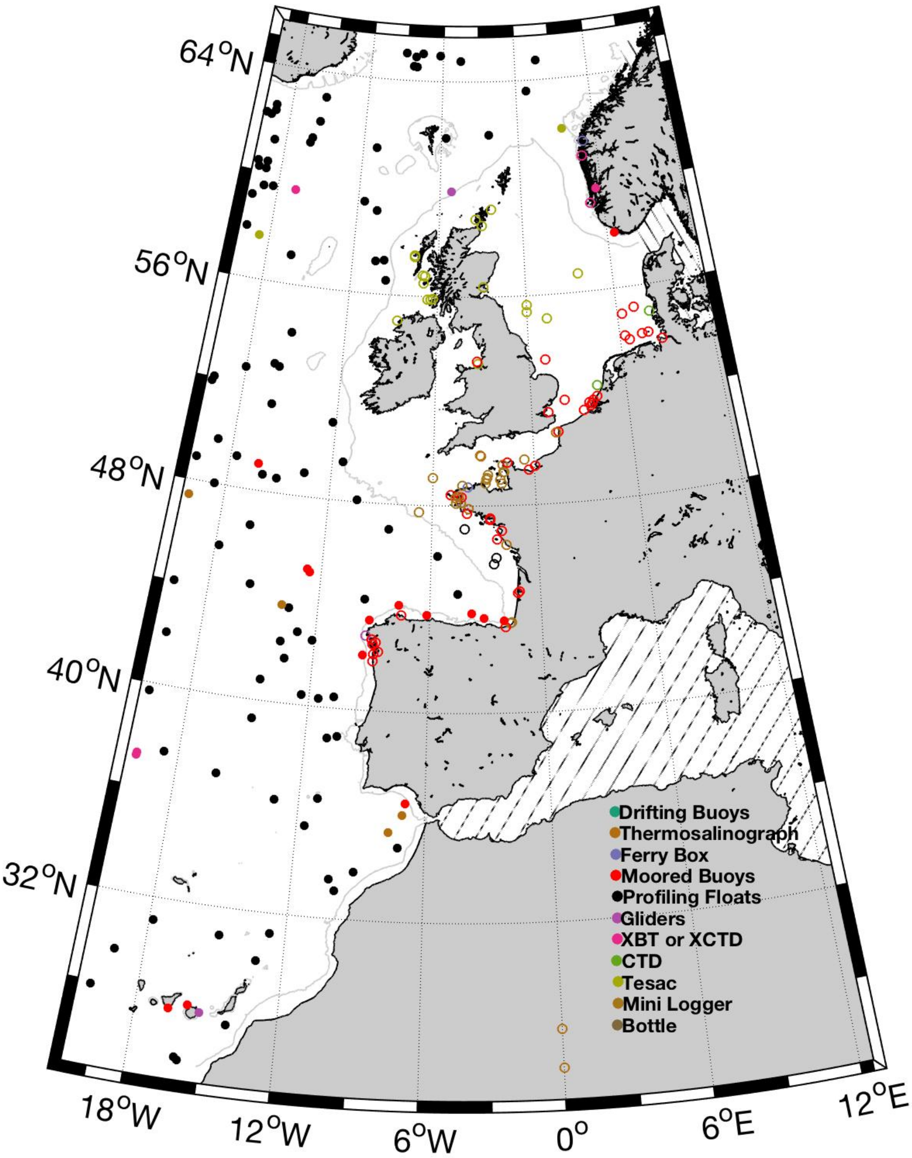

Figure 3 Distribution of in-situ platforms measuring Salinity, during 2017. The light grey line represents the 200m depth isobath considered as a limit between coastal and open ocean waters.

Ocean currents

There is a total of 110 in-situ observing platforms measuring Currents in the defined area during 2017. Current possibly derived from Argo profiler drift are not considered in this analysis as we focus on the measurements of surface currents or surface layer currents. 77 of those platforms are open ocean platforms and 33 were coastal platforms.
Geographical distribution of these observing platforms are given in Figure 4.

For ocean currents, observations in open ocean are coming mainly from drifters with a total of 66 platforms in 2017 (
Table 3). Over continental shelves, moorings equipped with ADCPs are the main source of observations. The map of observed currents available in Emodnet physics portal for 2017 shows that in-situ currents measurements remain sparse in both coastal and open ocean.
Altimetry satellites provide successful and continuous monitoring of ocean currents (altimetry-derived geostrophic ocean currents) in the open ocean, whereas they fail to provide successful monitoring in the coastal areas. For surface currents, measurements from coastal HF Radars are improving the observations of surface currents near the coast, up to 100Km (see the EuroGOOS HF Task Team inventory: http://eurogoos.eu/high-frequency-radar-task-team/).

Table 3 Number and type of Open ocean and Coastal platforms measuring Currents.

Observing Platform	Number of Open ocean Platforms (deeper 200m depth)	Number of Coastal Platforms (shallower 200m depth)
Drifting Buoys	66	5
Moorings	11	15
Ferrybox	-	13
Total	**77**	**33**

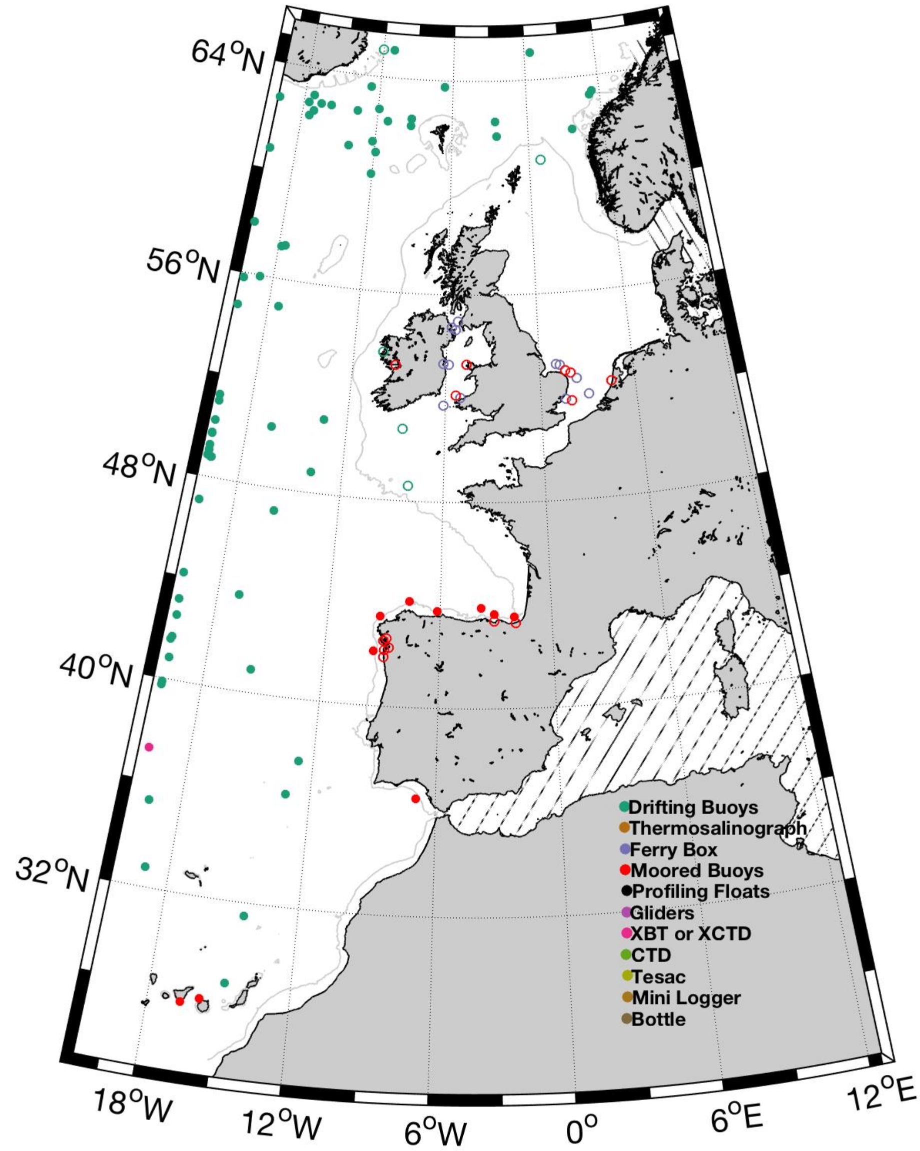

Figure 4 Distribution of in-situ platforms measuring Currents, during 2017. The light grey line represents the 200m depth isobath considered as a limit between coastal and open ocean waters.

Sea level

There is a total of 224 in-situ observing platforms measuring Sea-level in the defined area during 2017. All of these are coastal moored instruments/tide gauges. There is one instrument classified as an open ocean platform in Figure 5, located in the Canary Islands, where the shelf (region shallower than 200m depth) is extremely narrow compared with other shelf regions.
Distribution of the tide gauges are given in Figure 5.
Sea level has been historically observed along most of the European coasts. Sea level observation, combined with satellite observations is an example of organised observing system. Near future effort will be focused in sustainability issues maintaining infrastructures providing data for long time periods.

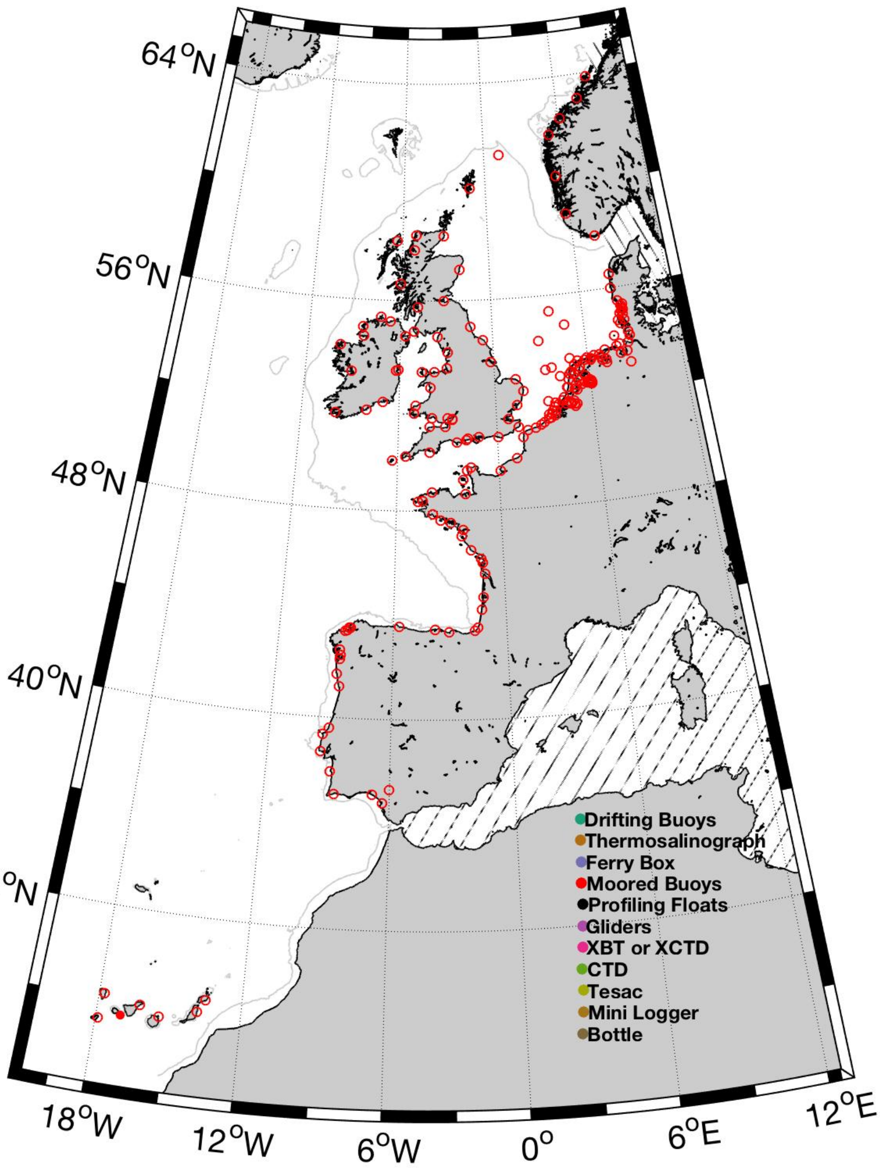

Figure 5 Distribution of in-situ platforms measuring Sea level, during 2017. The light grey line represent the 200m depth isobath considered as a limit between coastal and open ocean waters.

Waves

There is a total of 153 in-situ observing platforms measuring Waves in the defined area during 2017. 30 of these platforms are open ocean platforms and 123 are coastal platforms. Distribution of these observing platforms are given in Figure 6.
Except for some reference moorings supported, for example by meteorological institutes, most of the wave observing networks are located in coastal areas.

Table 4 Number and type of Open ocean and Coastal platforms measuring Waves.

Observing Platform	Number of Open ocean Platforms (deeper 200m depth)	Number of Coastal Platforms (shallower 200m depth)
Moorings	20	121
Drifting Buoys	10	2
Total	**30**	**123**

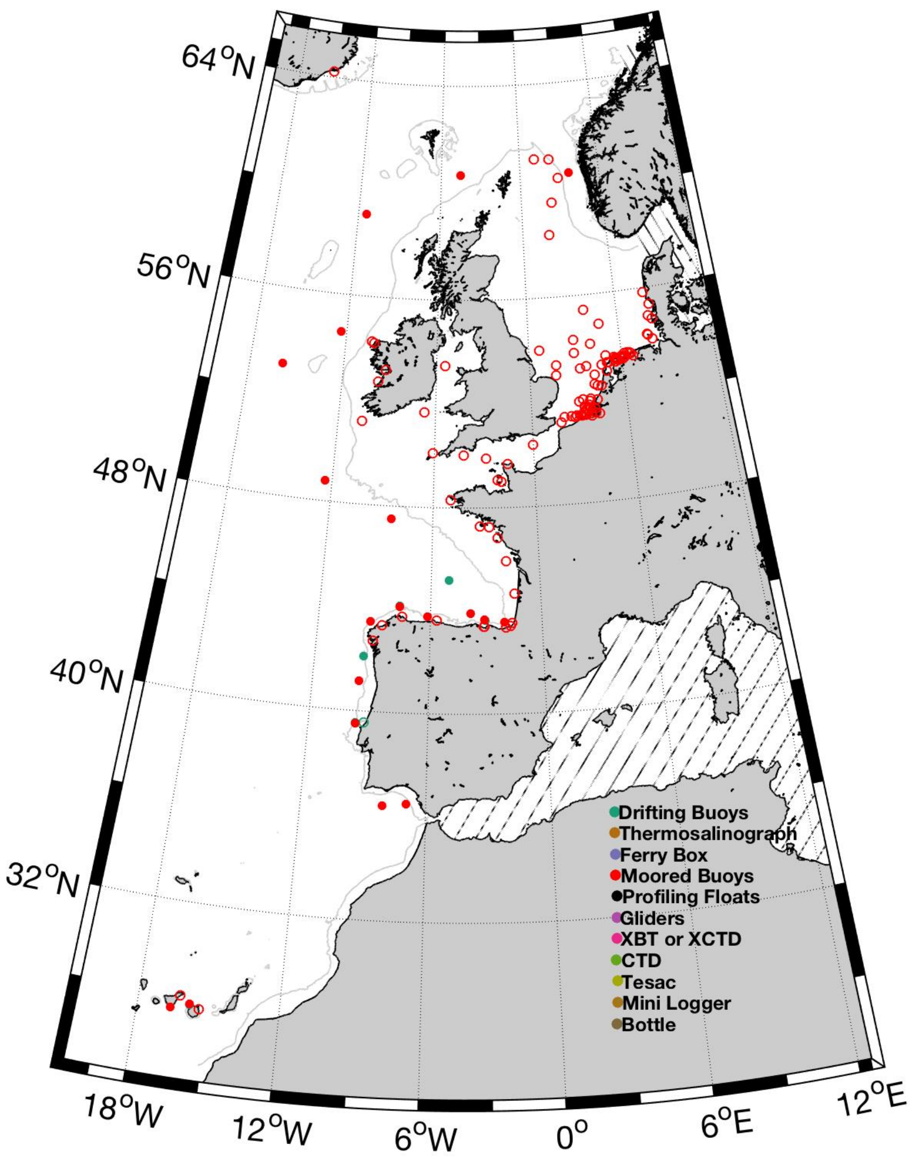

Figure 6 Distribution of in-situ platforms measuring Waves, during 2017. The light grey line represents the 200m depth isobath considered as a limit between coastal and open ocean waters.

Oxygen

There is a total of 41 in-situ observing platforms measuring Oxygen in the defined area during 2017. 11 of these are open ocean platforms (8 profiling floats, 1 glider and 2 moorings) and 30 are coastal platforms (28 Moorings, 1 Ferrybox and 1 Mini Logger). The Argo programme aims to increase the number of profiling floats with O_2 sensing capability in the near future.

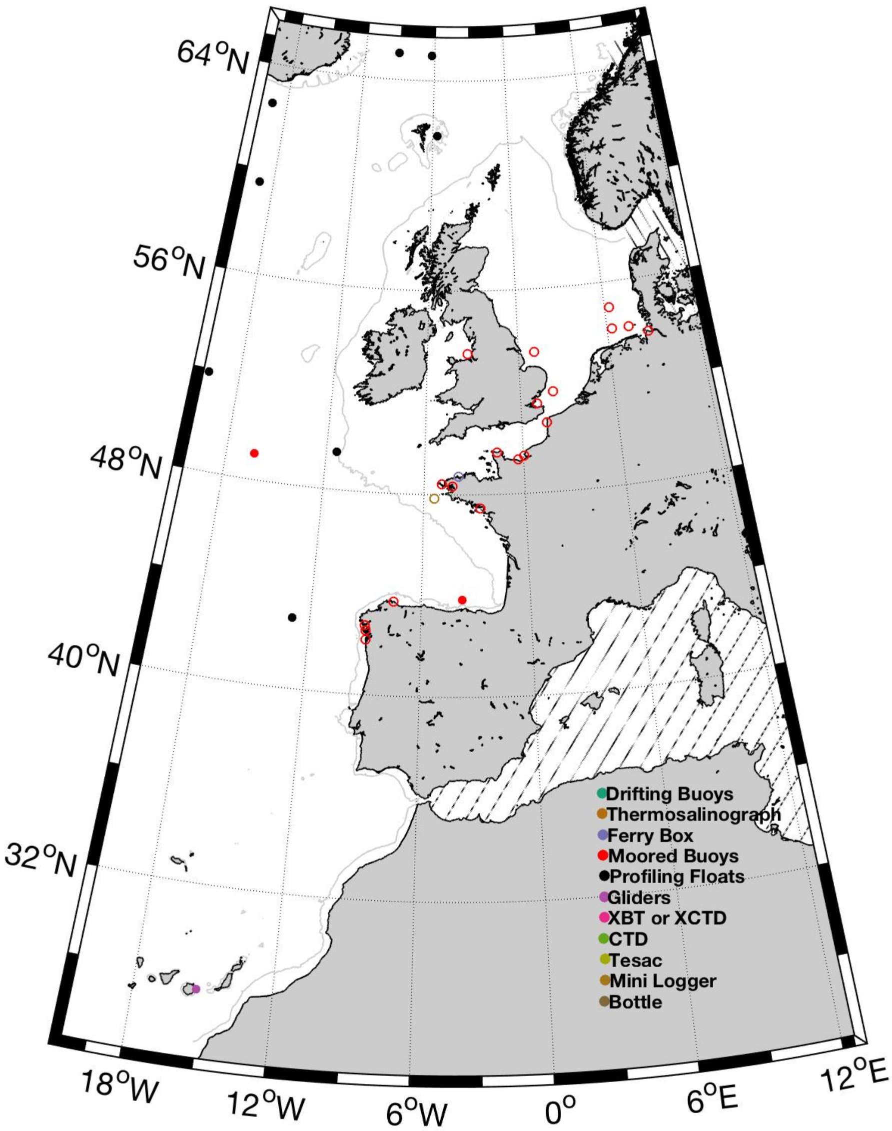

Figure 7 Distribution of in-situ platforms measuring Oxygen, during 2017. The light grey line represents the 200m depth isobath considered as a limit between coastal and open ocean waters.

Chlorophyll

There is a total of 23 in-situ observing platforms measuring Chlorophyll in the defined area during 2017. Eight of these (4-profiling floats, 3 moorings and 1 glider) are open ocean platforms and 15 are coastal platforms (10 Moorings, 1 Mini logger, 1 Glider, 1 CTD and 2 Ferrybox).

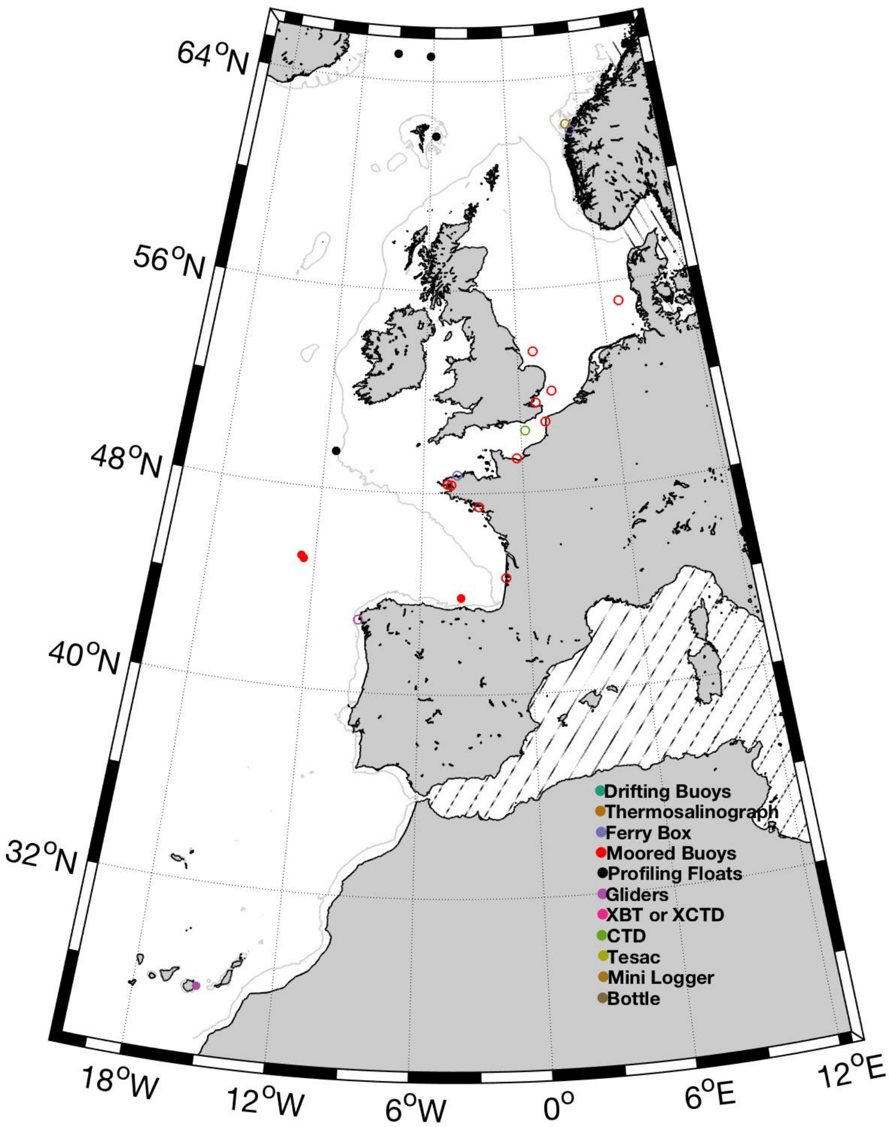

Figure 8 Distribution of in-situ platforms measuring Chlorophyll, during 2017. The light grey line represents the 200m depth isobath considered as a limit between coastal and open ocean waters.

An example in the Bay of Biscay at the interface between coastal and open ocean

Here we present an example case in the Bay of Biscay, with a particular focus on the use of in-situ measurements in identifying possible cross-shelf exchanges (*i.e.* ocean fluxes between the coastal and the open oceans). In order to explore the different ocean dynamics (coastal, slope and open ocean circulations) in the considered region, area of interest (Figure 9) are further divided into subregions according to bathymetry (Figure 10). These sub-regions are investigated using all available in-situ measurements of temperature and salinity.

The number of salinity profiles (Figure 12, Figure 15, Figure 18) is smaller than the number of temperature profiles (Figure 11, Figure 14, Figure 17) in the monthly distribution maps (considering good quality data).

For the considered time period (2007-2014), R1 and R3 are rather well covered compared to R2. Measurements in R1 are mostly from profiling floats, whereas the measurements in R2 and R3 come from moorings, XBT's, CTD casts from vessels and mini loggers (fishery observing system from the RECOPESCA programme).

The number of profiles from the existing networks are sufficient to obtain general information on R1 and R3, however due to lack of data, background state for R2 is not clear, particularly for salinity. The signal in salinity is noisy due to interactions with surrounding regions, particularly the freshwater influence from R3.

With the available information, it is only possible to distinguish an exchange event, induced by an eddy in R1, grabbing water from R2, which is seen in temperature and salinity anomalies in R1, further supported by satellite data and model outputs.

This pilot study gives important messages in terms of data gaps in the region:

-Despite open ocean (mainly Argo profilers) and continental shelf (mainly CTD's, moorings and fishery observing networks) observing networks with a good spatial coverage, the shelf break region is poorly sampled, mainly with residuals of the open ocean and shelf observing networks.

-There is a general need for more platforms with salinity sensors.

-At this point, fishery observing networks (mini loggers) are the most effective network for shelf break monitoring.

-However the mini logger data displayed more bad quality data than other networks. Thus, despite their undeniable contribution in shelf-break sampling, there is a need for a more reliable sensor technology, for interoperability with other networks.

-Glider experiments can significantly contribute to process-oriented studies over the shelf break.

-Profiling floats are a mature network for open ocean, and coastal profiling floats are an emerging network for coastal ocean. Coastal moorings are also a mature network for the coastal ocean. However, there are no dedicated observations above the continental slope where a complex ocean circulation drives the exchanges between open and coastal oceans. For example, the narrow region with a quickly changing depth does not allow observations from profiling systems from Argo programme.

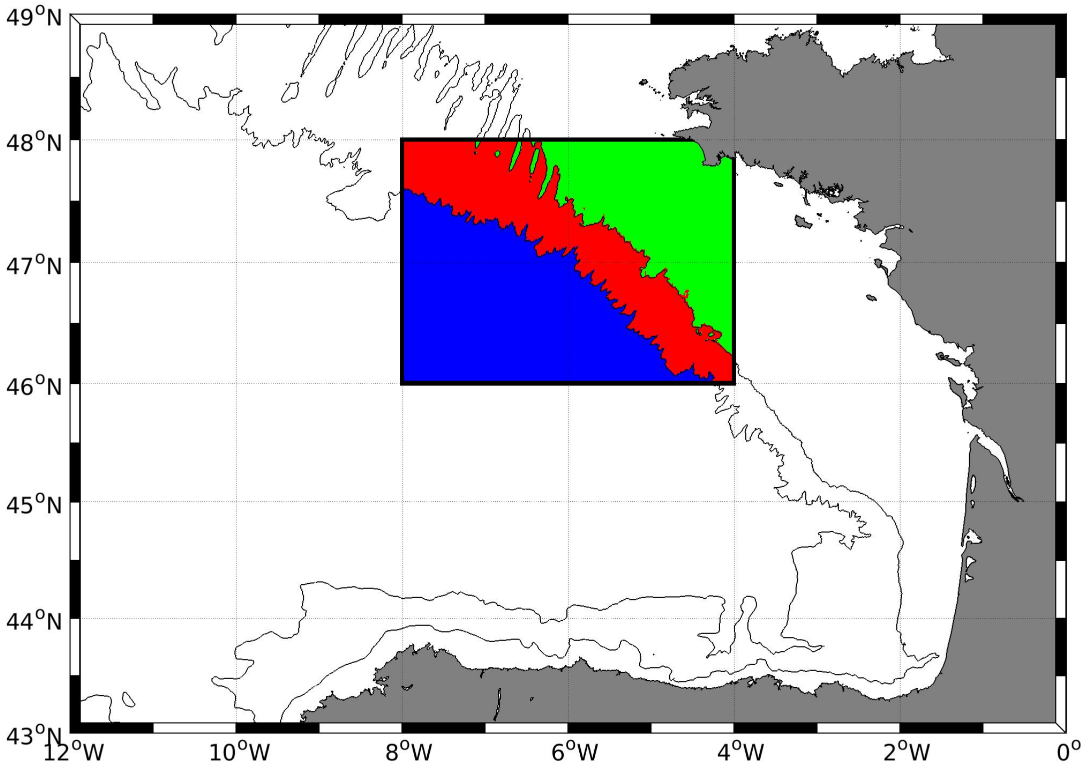

Figure 9 Example domain in Bay of Biscay, divided into three regions: Deep (R1 - blue), Shelf-break (R2 - red) and Shelf (R3 - green). Light grey lines represent the 150m and 2500m depth contours.

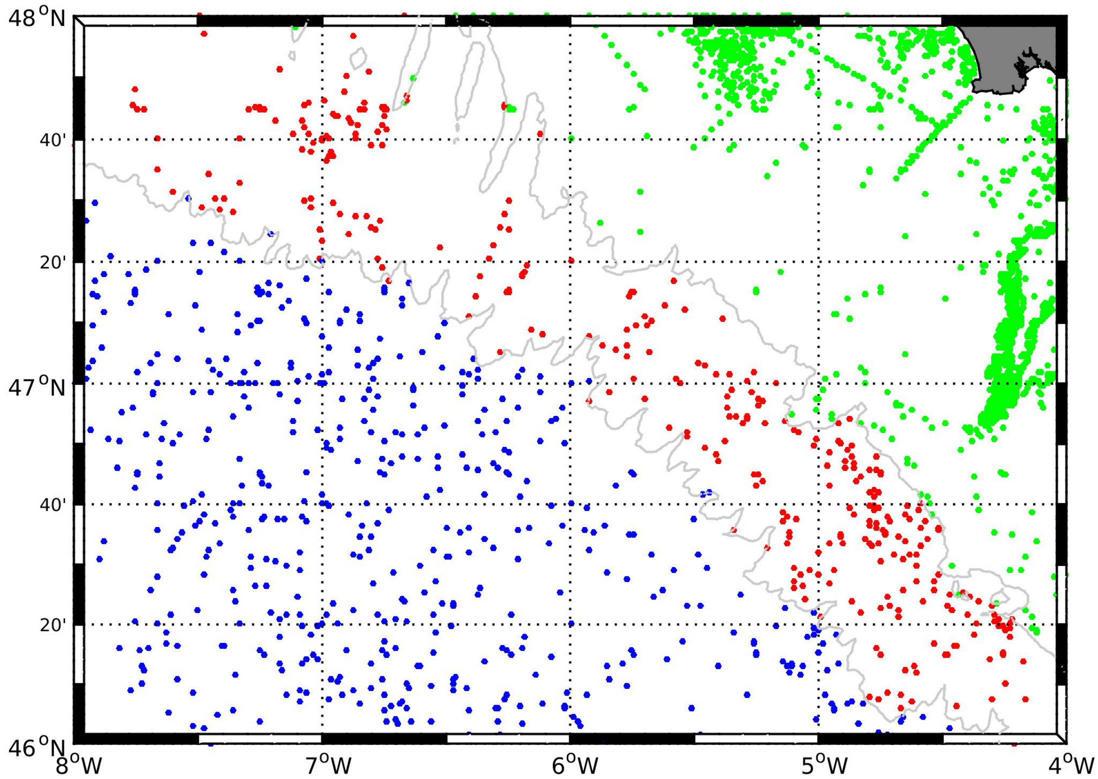

Figure 10 R1 (blue profiles), R2 (red profiles) and R3 (green profiles)

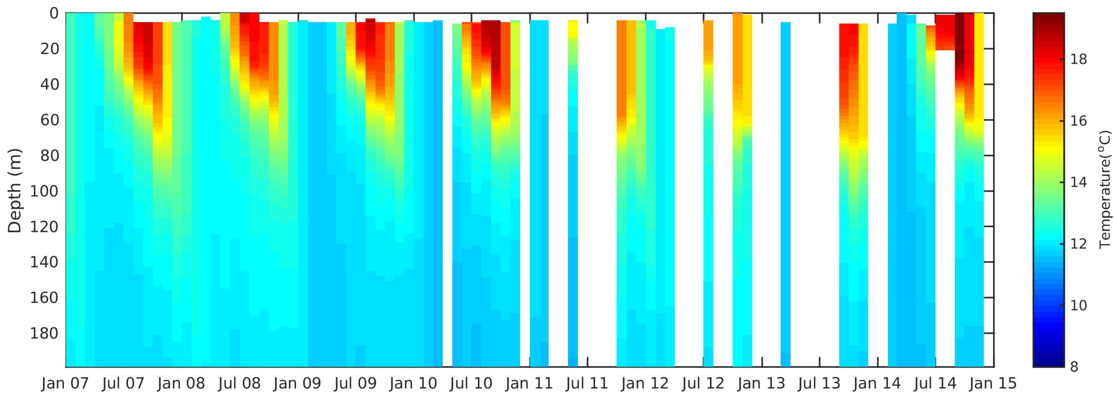

Figure 11 Monthly distribution of Temperature in R1. White areas represent periods where data are missing.

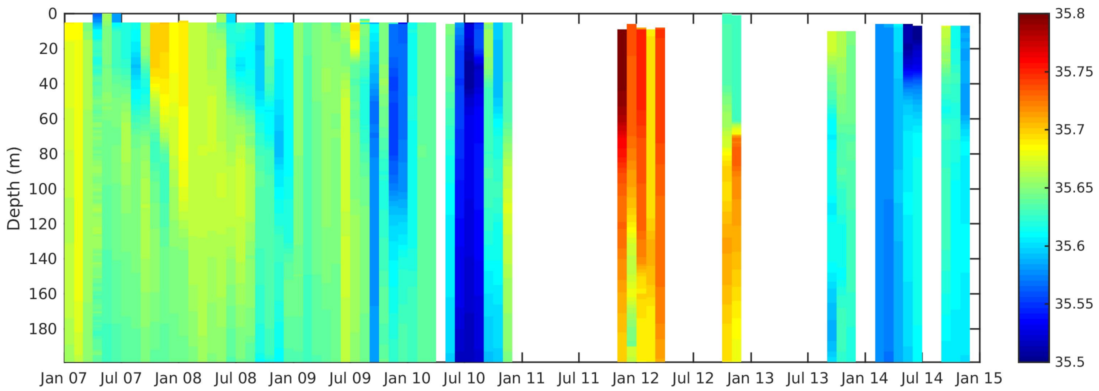

Figure 12 Monthly distribution of Salinity in R1. White areas represent periods where data are missing.

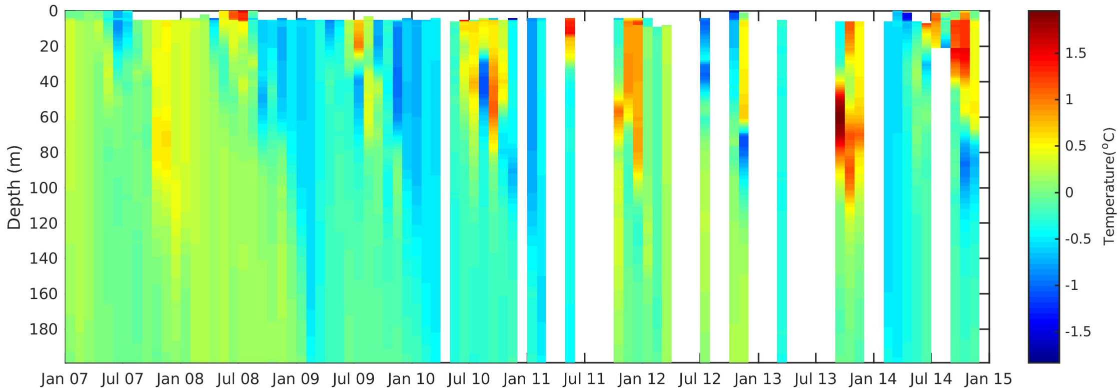

Figure 13 Monthly distribution of Temperature Anomaly in R1. White areas represent periods where data are missing.

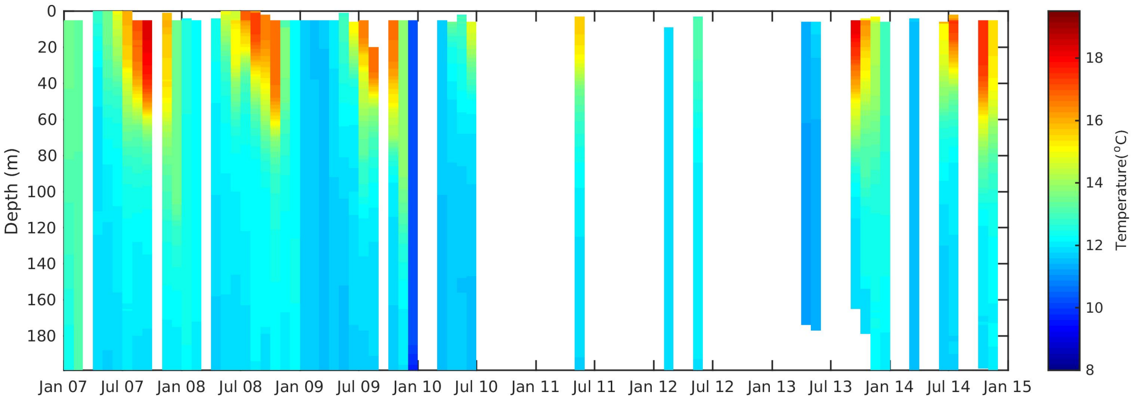

Figure 14 Monthly distribution of Temperature in R2. White areas represent periods where data are missing.

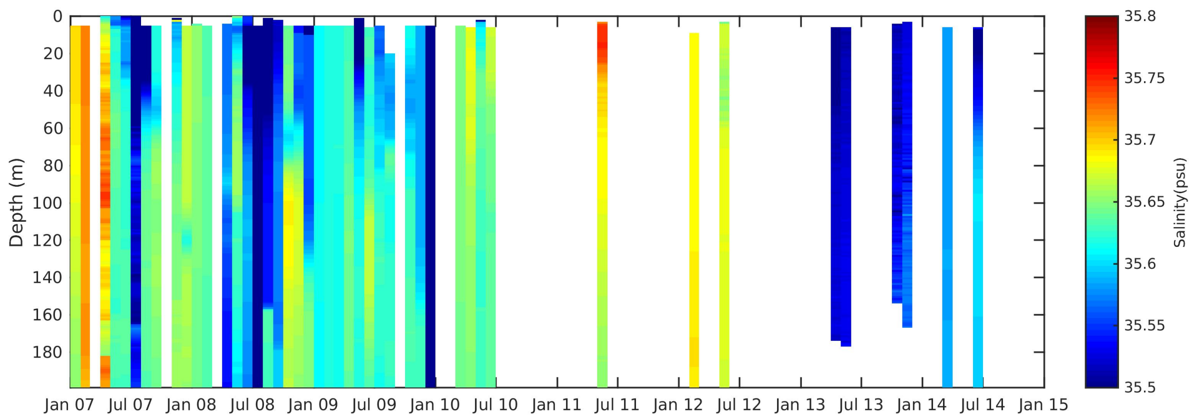

Figure 15 Monthly distribution of Salinity in R2. White areas represent periods where data are missing.

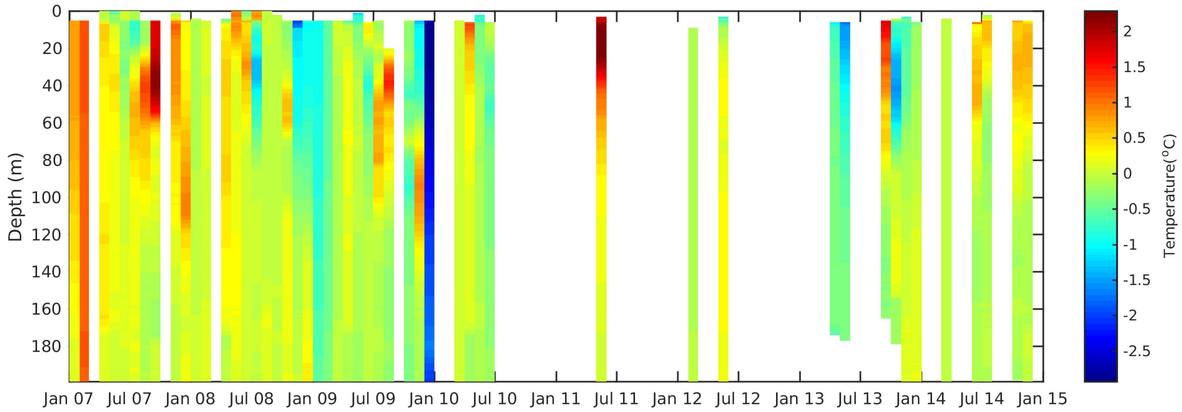

Figure 16 Monthly distribution of Temperature Anomaly in R2. White areas represent periods where data are missing.

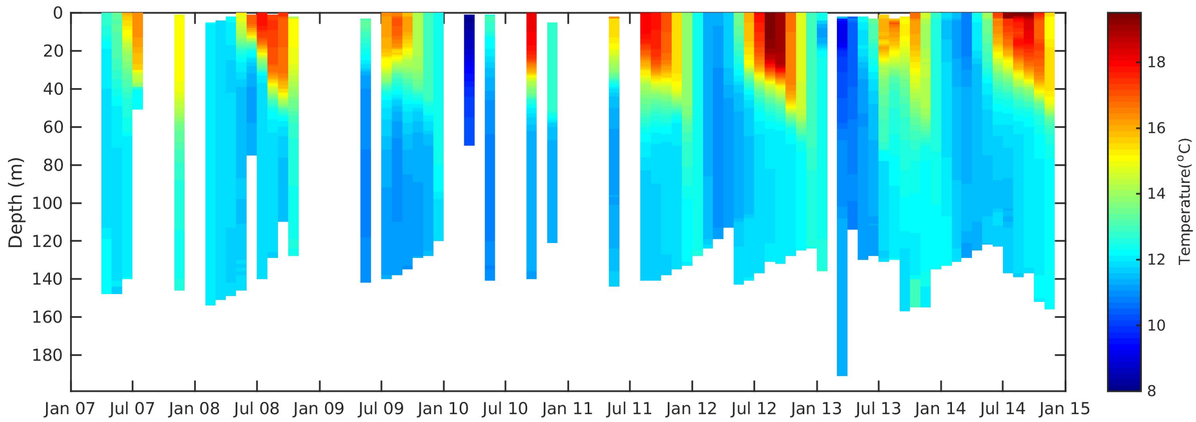

Figure 17 Monthly distribution of Temperature in R3. White areas represent periods where data are missing.

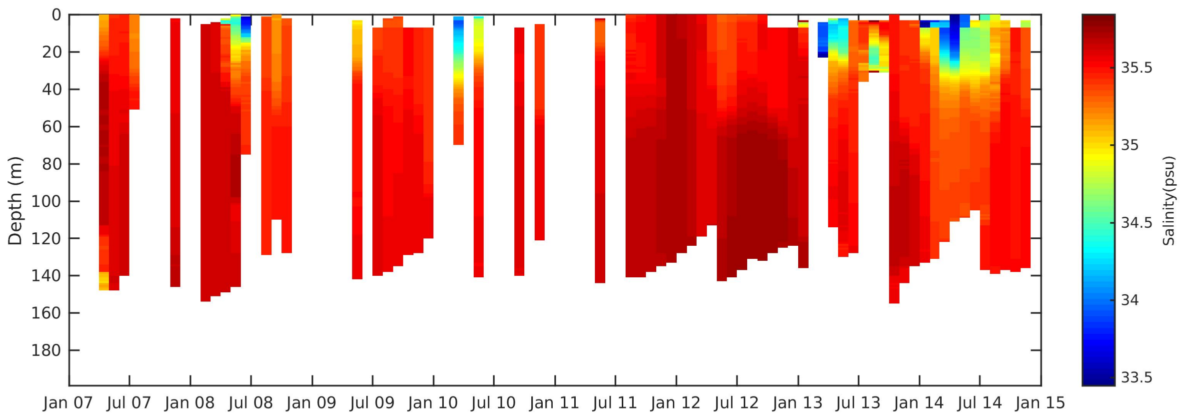

Figure 18 Monthly distribution of Salinity in R3. White areas represent periods where data are missing.

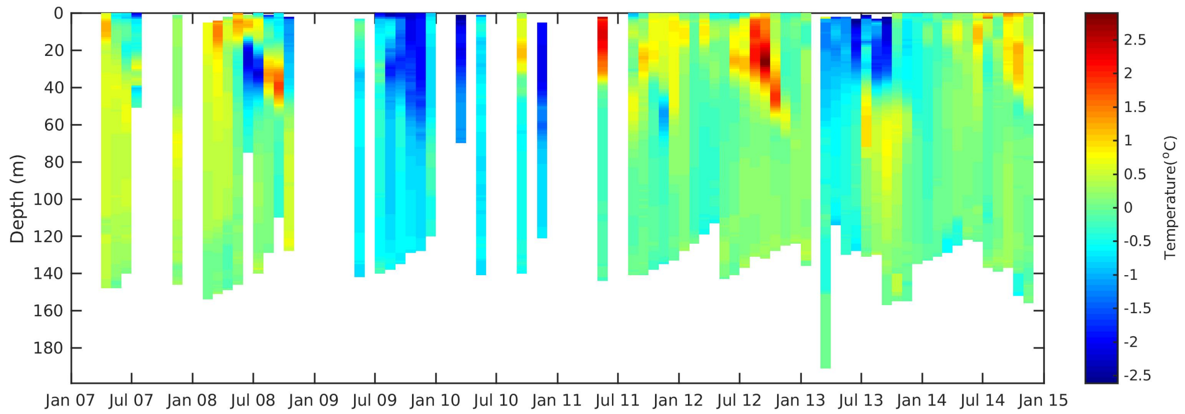

Figure 19 Monthly distribution of Temperature Anomaly in R3. White areas represent periods where data are missing.

Observing Gaps between coastal and open oceans: AtlantOS recommendations

Following the classification described in the WP1 from AtlantOS (Deliverable 1.3) for Gap Analysis, four aspects need to be addressed. The first gaps are related to the **observing networks**. In the present deliverable, this first issue will be considered as an evaluation of the continuum between coastal and open ocean observing networks. The second aspect is related with the **data availability**. This point can be considered as one key pillar of tomorrow's integrated observing system. The third issue is the **sustainability** of observing system. Indeed, long term observation makes sense only if infrastructures can be deployed over long time periods. The fourth aspect is dedicated to the **technology**. Technological improvements must stay closely linked with scientific issues to be addressed.

When those four aspects are considered in terms of synergy between coastal and open ocean, the following main recommendations needs to be assessed.

Observing networks

Following previous section, an **insufficient spatial coverage** clearly appears **between the near-coast and open ocean observing systems**. For example, Temperature and Salinity measurements come mainly from profiling floats and drifting buoys in the open ocean whereas moorings and mini loggers are the most significant platforms in coastal waters. Considering their capability to include additional sensors and their deployment over long periods, moorings can be considered as one of the **most effective coastal platforms**. However, **most of the moorings are located near-shore** and the number of **deeper moorings are limited**. At this point, **mini loggers (particularly fishery observing systems)** play an important role as **shelf and shelf-break observing platforms**.
In coastal regions, most of the observing networks cover surface layers (not shown). Although some moorings are extending to the whole water column, the deployment of such systems remains scarce. The deployment of autonomous systems for operational oceanography, like coastal profilers

or gliders, is limited due to intense human activities (*e.g.* fisheries, recreational activities, transports) in coastal waters.
In the present analysis, a lack of observations from platforms operated during scientific cruises or targeted experiments (*e.g.* glider, CTD casts) is observed. This may suggest that more connections between international datasets are needed as those experiments are driven in the considered regions.

Regular cruises and moorings appears as an efficient way conducting coherent measurements both on the coastal and open ocean. Such observing platform has been proven to be effective for temporal variability, observing intermediate water masses and intrusions of slope currents.

This insufficient spatial coverage (for most of the variables) leads to a general **lack of shelf break and shelf sampling**. Physical processes in the coastal ocean are more complex than in the open ocean, thus require an adequate sampling. Continuous monitoring of the shelf waters is crucial supporting the continuity and success of active **operational numerical forecast models**. Current models are quite successful for the open ocean, particularly due to data availability through continuous measurements (Argo and satellites). However, there is an urgent **need for coastal data (especially near-real-time),** where such systems are not effective, for **assimilation and validation purposes**. Currently, small-scale coastal models depend on regional level measurements (*e.g.* HF radars, gliders etc.), and there is lack of a coherent sampling scheme with the open ocean. There is also a general need for ocean current measurements for the models.
Another need for continuous shelf monitoring is to monitor phenomena as Harmful Algal Blooms (HABs). Occurrence and advection of some HAB events are related with the shelf circulation. This lack of HABs observation in shelf waters is strongly linked to **a lack of biogeochemical or biological observations and data**. As for the open ocean, those biogeochemical or biological information are not available in coastal regions except near coast where regular sampling are performed. Mature observing technologies to observe oxygen, nutrients, Chlorophyll-a, carbon or pH observations exist, but they are not extensively deployed.

Concerning the **best practices** followed for coastal and open ocean observations, **harmonization actions** have been started but they need to be extended to the whole range of observing networks (particularly diverse in coastal area). Some “coastal specific” parameters, like turbidity, will need dedicated focus to reach the same level of harmonization as for temperature.

Data availability

Considering data availability, identified issues for the open ocean (cf. Deliverable 1.3) can be extended for coastal observing systems. Non-open data policies limiting the release of data, datasets obtained by private companies not being available, holding back data due to publishing strategy or data not released for lack of Quality Control, are some of many reasons that limit the open and free access to marine data. Under the pressure of European directives (*e.g.* INSPIRE), which aim opening the access to public data, national efforts are deployed. For example, in France, a significant effort is dedicated to improve the interoperability between ocean data centres. We can then observe the development of national research infrastructure dedicated to data availability. Links between the ocean community and the European ecological monitoring groups linked with the EU WFD WISE[3] database can also improve the data visibility.

[3] WISE: https://www.eea.europa.eu/data-and-maps/data/wise-wfd-2

Considering the coastal/open ocean tandem, **coastal data availability remains more limited** because coastal observing systems are supported at national levels. Furthermore, some initiatives on data are not extended at European or international level (e.g. data remains stored on national databases not connected with European data portals). For the open ocean, international collaborations are developed upstream sensor deployments related with ocean regions targeted.

Sustainability

Sustainability issues for different observing platforms are very heterogeneous as they rely on a wide range of different funding mechanisms depending on the particular networks or systems (HF radars, moorings , ships etc..). Both in- situ ocean observations funds in coastal or open ocean are based on infrastructures mainly supported by **national agencies** or **time-limited research projects**.
Estimations of costs are necessary to show that observing ocean from coast to open ocean has a low cost to society compared with other infrastructures (*e.g.* roads), and how they provide **benefits for the society**.

Technology

From the technological point of view, there is a need for **standardizing technological modules** for continuous, affordable and efficient monitoring systems, particularly for the coastal ocean. Indeed, biofouling issues in productive coastal waters impose the use of efficient **biofouling protection** and more frequent operations at sea (*e.g.* when a PIRATA mooring in Tropical Atlantic is visited once a year, a coastal mooring needs a visit typically every 3 months. For example, more frequent maintenance is required for biogeochemical and optical sensors).

Concluding remarks

The overall technological objective in the following years will be to improve the **harmonization** of coastal and open ocean observing networks. Where today, spatial and temporal gaps or gaps in measured parameters are observed, tomorrow the synergy between those observing system will be improved.
The data access remains a limitation in the development of integrated observing systems from the coast to the open ocean. Actions to improve the data availability and access need to be supported.
Bridges between coastal and open ocean initiatives need to be sustained to develop efficient long term observing systems.

Glossary

- EOV: Essential ocean variable
- GTS: Global Telecommunications System
- CTD: Conductivity-Temperature-Depth
- TESAC: In this document, Tesac represents all profiles transmitted through GTS, including ship-measurements, gliders, marine mammals etc. Different platforms are classified as Tesac within Emodnet data portal.
- Mini-logger: Mini loggers represent low-cost mini measurement systems. All mini-loggers in this document belong to fishery observing systems. Thus mini loggers represent fishery-observing systems.
- Moored buoys: Represent all moored buoys and tide-gauges.